5.U. Liquid crystal [redacted] spot detection with infinitesi[redacted] temperature control

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BACKGROUND OF THE INVENTION

There are two distinct ways of using the liquid crystal properties for ~~hot spot detection~~ analyzing integrated circuits. These are:

(A) using the light scattering property of ~~the cholesteric~~ cholesteric liquid crystal (see reference 3 & 4), and

(B) the phase transition property of the liquid crystal (see reference 1 & 2).

This invention uses the phase transition property of the liquid crystal. Therefore, the discussion shall be limited to the phase ~~transition type of the hot~~ to the hot spot detection method.

There are three kinds of liquid crystals: cholesteric, nematic and smectic. Both the cholesteric and nematic liquid crystal have been used for detecting hot spot (see reference 1 & 2). John Hiatt (see reference 1) reported that with a cross polarized light and a LC-127 cholesteric liquid crystal, he obtained a spatial resolution of ten to twenty microns. Also, the heating was not used, therefore the lowest ~~dectectable~~ detectable power of the hot spot is in the range of one hundred to two hundred milliwatts. E.M. Fleuren (see reference 2) reported the use of a ~~N-5~~ N5 nematic liquid crystal phase to ~~to~~ detect ~~a~~ hot spots. The particular nematic liquid he used is called N5. He used a P.I.D. control and achieved a constant temperature ~~of~~ of 0.1~~degree~~ degree celsius ~~Centigrade~~ to a specified temperature. He could routinely detect a hot spot of 100 microwatts or more, with the P.I.D. control.

3 However, by chance, if the liquid crystal's ambient temperature happens to be much less than 0.1 degree celsius ~~Centigrade~~ (say a 0.005 degree celsius ~~Centigrade~~) below the liquid crystal phase transition

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temperature, he could detect a lower power hot spot. He managed to detect a hot spot of 3.6 microwatts once.

For a liquid crystal hot spot detection method, the lowest amount of integrated circuit energy required ~~requires~~ to induce a liquid crystal phase transition is proportional to the difference ~~dfference~~ between the liquid crystal phase transition temperature and the liquid crystal film's temperature. Before this invention, the temperature control process is to keep the liquid crystal temperature constant. The disadvantage of the constant temperature method was ~~is~~ that there is no instrument that could control a temperature infinitesimally close to a specified ~~temperature~~. /a1 Also, prior to this invention, the ~~mode~~ heating mode was ~~is~~ either conductive (see reference 2) or no heating at all (see reference 1). The liquid crystal film's temperature responds slowly to the conductive heat transfer, because a large poor heat conductor exists between the liquid crystal film and the conductive heating system. The same large poor heat conductor induces an uneven temperature profile on the liquid crystal film, thus reducing the sensitivity ~~sensistivity~~ of the liquid crystal hot spot detection method.

/a2 ~~The invention use a varying temperature control method~~. This method enables the liquid crystal film's temperature to be brought to infinitesimally close below to the liquid crystal phase transition temperature. Therefore, a low power hot ~~hot~~ spot with only one or two microwatts could be routinely detected. /a3 The sensitivity of this invention was helped by using a pulsing input to the hot spot. /a4 The difficulty arising from the inability to differentiate between a voltage induced blinking and a hot spot induced

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Ins a5 blinking was solved by ~~the invented varying temperature control method~~. a5

Po (*) Reference 1: John Hiatt, "A Method of Detecting Hot Spots on Semiconductors using Liquid Crystals." 19th Annual Proceedingsof the IEEE Reliability Physics Symposium, 1981, Pg. 130-133.

Po * Reference 2: E.M. Fleuren, "A very sensitive, simple analysis technique using nematic liquid crystals," 21st Annual Proceedingsof the IEEE Reliability Physics Symposium, 1983, Pg. 148-149.

Po (*) Reference 3: J.L. Fergason, "Liquid crystals in nondestructive testing," Applied Optics, Vol.7, ~~no~~ No.9, sept. 1968, Pg. 1729-1737.

Po (*) Reference 4: G.D. Dixon, "Cholesteric liquid crystal in nondestructive testing," Material Evaluation, June 1977, Pg.51-55.

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SUMMARY OF THE INVENTION

Ins a6 ~~Both the collimating~~ of the radiative heating light source and the direct overhead heating of the liquid crystal film have helped the formation of an even temperature profile on the liquid crystal film. Both the rapid response of the heating filament temperature and the direct overhead heating have helped to create a rapid temperature response from the liquid crystal film. The method of turning on and then turning off the radiative heating light source method allows the liquid crystal temperature

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to rise beyond and then drop below the phase transition temperatures of the liquid crystal. While the liquid crystal temperature rises ~~rising~~ across a phase transition temperature, there exists a limited length of time window when the liquid crystal temperature is arbitrarily ~~arbitrary~~ close to the liquid crystal phase transition temperature . During this limited length of time, an infinitesimally small heat dissipation from the location in the integrated circuit to the ~~circuit in the~~ liquid crystal film could induce a localised phase transition in a liquid crystal film. In other words, the turning on and then turning off the radiative heating light process enables the temperature of the liquid crystal to be brought within an arbitrarily ~~arbitrary~~ small range of a pre-specified temperature, for a limited length of time window. For example, with a carefully selected power level of the radiative heating light, the liquid crystal temperature is brought to less than 0.001 A7 ~~degree centigrades for~~ more than a few seconds. 16

Ins A7 Ins A8 Essentially, there is no limit A8 ~~how close this invention can~~ control a temperature to within a specified temperature. Therefore, in the application of this invention to the liquid crystal hot spot detection method, the lowest wattage of a detectable hot spot is not limited by the ability to control the temperature of the liquid ~~temperature the liquid~~ crystal film, but by the width of the temperature bands of the liquid crystal phase transition temperatures. Prior to this invention, the lowest wattage of a detectable hot spot was limited by the ability to control the temperature of liquid crystal film.

One of the nematic liquid crystals ~~crystal~~ used for this invention is 4 cyano- 4' hexyl-biphenyl. It is sold by E.M. Chemical under the

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trade name of K-18 nematic liquid crystal. I found it has 4 phase transition temperatures; ~~transition temperatures,~~ the temperature band width of each phase transition ~~transitions~~ is estimated to be on the order of ~~be the order of~~ 0.001 degree Celsius ~~centigrades~~. All the phase transitions lie within 28.5 and 30.0 degree Celsius ~~centigrades~~. The exact temperature of each phase transition is not measured, and is not important to this invention. The K-18 nematic liquid crystal is not the only chemical that works ~~work~~ well for this invention.

The selection of the electrical ~~electrical~~ input power at 1.2 Hz and at 50% duty cycle to the hot spot of the die or wafer produces the optimal observable and differentiable hot spot blinking effect. The process of turning the radiative heating light on and off permits the ambient temperature of the liquid crystal to vary with the time. Below the phase transition temperature of the liquid crystal, the size of the hot spot induced blinking increases as the ambient temperature increases, but the size of the voltage induced blinking does not respond to ambient temperature changes. The invented process of ~~The process~~ turning on and then off the radiative heating provides a means to differentiate the hot spot induced blinking from a voltage induced blinking.

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DCL BRIEF DESCRIPTION OF THE DRAWING

Figure 1 shows the set-up of the invention.

Figure 2 shows the temperature of the liquid crystal film ~~layer~~ and the heating up time

DCL DETAILED DESCRIPTION OF THE INVENTION

Use a signal generator to generate a low frequency signal 1. (refer to figures 1 and 2) The frequency of signal 1 ~~The signal frequency 1~~ is 60 hertz or lower. The preferred signal frequency of signal 1 is around 1.2 Hz. The advantages of 1.2 Hz are (a) 1.2 Hz is slow enough

a for visual observation; (b) 1.2 Hz is ~~very close to human heart~~ close to the human heart beat rate; therefore ~~human~~ humans can easily identify a 1.2 Hz when encountered; and (c) 1.2 Hz is fast enough to form enough number of optical observation phase changes during a short "time window", in which only during the time window ~~the phase transition is possible.~~ the hot spot induced blinking is visible

Ins A'10 A10 ~~The signal frequency cannot be higher than 60 Hz, for which~~ human eyes cannot see an optical image change with a frequency higher than 60 Hz. The signal 1 is used to control a switch. The switch can be either a relay or a solid A11 ~~state switch. The switch 2~~ can be either an on/off switch or a variable switch. The on/off relay switch is the preferred switch, because the relay switch has no leakage current. The time lengths of the "on" mode and "off" mode of the ~~relay switch are~~ relay switch 2 is controlled by the wave form, the duty cycle, and the frequency of the signal 1. Any "on" and "off" mode time lengths would enable the invention to function. The pattern of the preferred "on" and "off" time lengths is: (a) the "on" time length and the "off" time length are equal, (b) the "on" time length and the "off" time ~~length each equal~~ lengths are each equal to 0.6 seconds. An equal time length produces a maximum optical resolution for observing A12 ~~the phase transition, at a given signal frequency.~~ The 0.6 seconds time length is chosen because the ~~phase transition is slow~~ hot spot induced blinking is slow enough for human eyes to observe, yet fast enough to generate enough number of observable phase transitions during hot spot induced blinking during the short time window. A13

The relay switch 2 is used to chop the D.C. 9 into square wave voltage 3 of 1.2 Hz and 50% duty cycle. The square wave voltage 3 is the input to the device under test 4, which is the die 17 or

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wafer 40 under test. The whole surface of the device under test has been spread with an even and thin ~~layer~~ film of nematic liquid crystal. The thickness of the liquid ~~crystal layer~~ crystal film 28 is adjusted to within a specific working range. The thickness adjustment and the thickness determination procedures consist of the following 3 steps:

Step T1: Adjust the light analyser 8 and the light polarizer 16 such that they optically cross polarized.

Step T2: Allow the liquid crystal to cool down below its phase transition temperatures.

Step T3: View the liquid crystal film 28 on ~~crystal thin film on~~ the device under test 4 from the viewing position 12, through the microscope 15. If the liquid crystal thickness is too thin or there is no liquid ~~or no liquid~~ crystal at all, the die surface and the liquid crystal would look very dark. Use syringe to spread more nematic liquid crystal onto ~~liquid onto~~ the die surface, and, use a sharp tipped paper corner to even out the nematic ~~liquid crystal. If the nematic liquid crystal film is~~ transparent but not showing any rainbow color, the nematic liquid crystal film 28 is too thick, use a ~~film is too thick. Use a~~ sharp corner paper to absorb the extra nematic liquid crystal. When the nematic liquid crystal film 28 ~~When the nematic liquid crystal~~ thickness reached the optimal working range, the nematic liquid crystal film 28 would ~~crystal film would~~ look very colorful and transparent. The optimal thickness of the nematics liquid crystal varies from one chemical to another. For the k-18 nematic liquid crystal , the optimal thickness is estimated to be in the range of a tenth of a mil.

A heat absorber 10 is placed on the path of the microscope

illuminating light. The cool light source 20 would have minimum interference on the liquid crystal temperature.

The heating system consists of two power supplies. The D.C power supply is preferred over A.C, because D.C. gives a steady ~~because a D.C.give a steady~~ voltage reading. Each of these power supplies has a variable power control, an on-off switch, a digital voltmeter in series, and one or more light bulbs in parallel. The preferred light bulbs are those with a co-planar filament. A co-planar filament is a requirement for an even heating light. The power supply 5 has a maximum output of around 50 watts; it is for coarse temperature control . The power supply 18 is for fine temperature control; it has a wattage of about a factor of 100 to 1000 lower than power supply 5. The dual switch 23 is capable of turning on or off both power supplies 5 and 18 concurrently. The heating lights 7, 24, 25 and 26 each has a co-planar filament and an objective lens. Ins A's The lenses are adjusted to form even and well ~~to form an even and well~~ collimated light beams. The beams are incident at an angle about 45 degrees from the axis vertical to the surface of the device under test 4. The preferred configuration is the heating lights 7 and 25 facing each other; the ~~each other, and the~~ heating lights 24 and 26 are also facing each other. This configuration will cancel the effects of the optical dispersion and the geometrical attenuation; these effects exist ~~attenuation, in which effect exists~~ in a single heating light design.

To operate the system, the following steps are taken:

Step S1: Adjust the curve tracer 14 to a desired power level. Turn on the on/off switch 27. Turn on the signal generator 13.

Step S2: Cross polarize the light analyser 8 and the light

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polarizer 16.

Step S3: Collimate the heating lights 7, ~~24, 25,and 26.~~ 24, 25 and 26.

Step S4: Place the device under test 4 on the microscope stage 29. Use a syringe to spread a layer of nematic liquid crystal film 28 on ~~crystal on~~ the surface of the device under test 4. Use a cut paper to adjust the thickness as well as to even out the nematic liquid crystal ~~layer~~ film 28 while viewing the nematic liquid crystal ~~layer~~ film 28 through viewing position 12. The nematic liquid crystal ~~layer~~ film 28 will ~~be in an optimal thickness~~ be at an optimal thickness when the nematic liquid ~~crystal 28~~ crystal film 28 shows a transparent and rainbow color all over the surface of the device under test 4.

Step S4: Adjust the power supply 5 till the solid state temperature sensor 21 reads a temperature of about 0.2 degree ~~centigrade~~ Celsius below the phase transition temperature 32. Allow 10 minutes for the nematic liquid crystal ~~layer~~ film 28 and die 17 to reach their equalibrium temperatures. Then select a setting for the power supply 18. Turn on the heating light switch 22. Time the length of time required for the nematic liquid crystal ~~layer~~ film 28 to cross the phase transition temperature 32. The longer the length of time 35, the ~~more sensitive of this~~ more sensitive is this invention in detecting a low wattage hot spot. I found that if the length of time ~~35 were~~ 35 was 10 minutes, a 10 microwatts of pointed source hot spot could be located. If the length of time ~~35 were~~ 35 was 15 minutes, a 2 microwatts of pointed source hot spot could be located. ~~however, further~~ However, further increase in the length of time 35 beyond 20 minutes would not further improve the sensitivity of this invention. At this temperature changing rate, the most limiting

factor is the temperature band widths of the phase transition temperatures ~~32,36~~ 32, 36 and 37. For K-18 nematic liquid crystal, each is estimated to be in the order of 0.001 degree celsius ~~centigrades~~. Considering ~~the~~ all the heat transfer properties of a typical ~~inrtegrated~~ integrated circuit and the K-18 nematic liquid crystal, the lowest detectable wattage of a hot spot is in the order of 1 microwatt.

After the desired power level setting of the power supply 18 is selected, turn off the heating light switch 22.

Step S5: Turn on the on-off switch 27 to allow the square wave voltage 3 to be input to the device under test 4. If the input voltage ~~were~~ was high enough (about 2 volts for K-18 nematics liquid crystal) , ~~the pulsing voltage would~~ the pulsing square wave voltage 3 would induce a cyclic disturbance in the nematic liquid crystal ~~layer~~ film 28. This cyclic disturbance will show up as a blinking appearance when viewed through the viewing position 12. The blinking is actually a combination of cyclic changes in transparency, brightness and colors. If the input wattage ~~were~~ was high enough to induce a cyclic localized phase transition, the appearance of this cyclic phase transition is very similar to pulsing voltage induced blinking ~~effect~~. I shall discuss in step S6 how to differentiate the two ~~effects~~ kinds of blinkings.

If the voltage ~~were~~ was lower than 2 volts, and if the input wattage ~~were~~ was high enough (typically in the order of 500 microwatts) ,only the localized cyclic phase transition alone would appear as a blinking spot. If the localized phase ~~tranasition~~ transition does not show up at 2 volts, additional heating (described in step S6) is required.

Step S6: Turn on the heating light switch 4. Allow the ambient temperature of the nematic liquid crystal film ~~layer~~ 28 to continue to rise. As the temperature continues to rise, the blinking spot induced by the localized phase transition will increase in size, or from nothing to an enlarging blinking spot. For the voltage induced blinking, the change of temperature change has hardly any effect on the blinking spot size, as long as the liquid crystal temperature is below the phase transition temperature 32. Those hot spots with higher power dissipation are the first to show up as hot spot induced blinkings ~~blinking spots~~. Those lower power dissipating hot spots are the last to show ~~up~~ the blinking appearance. If the hot spot was ~~were~~ at 2 microwatts, it would only show up for a few seconds, at just ~~seconds , at just~~ before the temperature of the nematic liquid crystal film 28 ~~layer~~ rises beyond the phase transition temperature 37. At any temperature higher than the phase transition temperature 37, both the voltage and hot spot induced blinkings cease to blink; also, the nematic liquid crystal film 28 ~~blink; Also, the nematic liquid crystal layer 28~~ becomes opaque and dark. This particular property is used to determine whether the temperature of the liquid crystal film 28 is below or beyond the phase transition temperature 37.

Step S6 can be repeated by turning off the light heating switch 22 to allow the ambient temperature of the nematic liquid crystal film ~~layer~~ 28 to drop below the phase transition temperature 32. Then repeat ~~the~~ step S6 from the beginning.

For a typical pointed source hot spot of a typical integrated circuit (for example, a filament type of short in the diode of a input pad of a DL 2416 integrated circuit), this method has been shown